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Subir Sachdev

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14. ABSTRACT
Recent experiments on ultracold atoms in optical lattices have opened a remarkable new window on the dynamics of quantum matter with long-range entanglement. The simplest paradigm of this is the boson superfluid-insulator quantum phase transition in two spatial dimensions. This project will study the theoretical representation of its dynamics by the methods of gauge-gravity duality. A holographic effective field theory method will be developed by comparing the results of computations in conformal field theory and gravity

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Subir Sachdev
UU	UU	UU	UU		19b. TELEPHONE NUMBER 617-495-3923

Report Title

Final Report: Dynamics of quantum matter with long-range entanglement.

ABSTRACT

Recent experiments on ultracold atoms in optical lattices have opened a remarkable new window on the dynamics of quantum matter with long-range entanglement. The simplest paradigm of this is the boson superfluid-insulator quantum phase transition in two spatial dimensions. This project will study the theoretical representation of its dynamics by the methods of gauge-gravity duality. A holographic effective field theory method will be developed by comparing the results of computations in conformal field theory and gravity

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Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
06/07/2013	1.00	Robert C. Myers, Subir Sachdev, Ajay Singh. Holographic quantum critical transport without self-duality, Physical Review D, (03 2011): 0. doi: 10.1103/PhysRevD.83.066017
06/07/2013	3.00	Debanjan Chowdhury, Suvrat Raju, Subir Sachdev, Ajay Singh, Philipp Strack. Multipoint correlators of conformal field theories: Implications for quantum critical transport, Physical Review B, (02 2013): 0. doi: 10.1103/PhysRevB.87.085138
TOTAL:	**2**	

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received		Paper
TOTAL:		

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received	Paper	
06/07/2013	2.00	Subir Sachdev. Quantum Phase Transitions, New York: Cambridge University Press, (05 2011)

TOTAL: **1**

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Philipp Strack	0.60
FTE Equivalent:	**0.60**
Total Number:	**1**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Subir Sachden	0.08	
FTE Equivalent:	**0.08**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period:	0.00
The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:.....	0.00
The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:.....	0.00
Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):	0.00
Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:	0.00
The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense	0.00
The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:	0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME PERCENT_SUPPORTED

FTE Equivalent:

Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Technology Transfer

U.S. Army Research Office STIR Award W911NF-12-1-0227

Dynamics of quantum matter with long-range entanglement.

P.I. Subir Sachdev, Harvard University

Final Report

This STIR project had a specific goal which lays the foundation of the long term project. The P.I. and collaborators have proposed [1] a "holographic" theory in the gravitational framework which can capture the finite temperature dynamics of a large class of quantum critical points. The theory is based upon a gradient expansion of an effective field theory, and the expansion has been carried out to fourth order. Each order in the expansion brings in a new free parameter. The present theory has 2 parameters, the gauge coupling e, and a leading non-linearity, which was called [1] γ. We argued that e could be fixed by the value of the high frequency conductivity, and the latter can be computed by the field-theoretical methods described above [2]. However, γ remains to be determined. The goal of the STIR was to compute the value of γ for the field theory appropriate to the quantum-critical point of the superfluid-insulator transition.

The computation of γ requires two separate analyses, which have since been published in Ref. [3]. First, in the holographic theory, we related γ to certain operator product expansion coefficients between the stress-energy tensor and two factors of the electrical current. This involved applying the prescriptions of gauge-gravity duality relating bulk correlations to correlators of fields on the boundary. Second, we computed this operator product expansion using the field-theoretic methods described in Refs. [2, 4]. This involved application of the $1/N$ expansion to the conformal field theory described by the Wilson-Fisher fixed point.

Our determination of γ opens the route to a parameter-free computation of various experimentally observable properties: frequency dependent conductivity, diffusion of tagged particles, non-linear transport, all of which can be measured in the ultracold atom experiments.

References

[1] R. C. Myers, S. Sachdev and A. Singh, "Holographic Quantum Critical Transport without Self-Duality," Phys. Rev. D **83**, 066017 (2011) [arXiv:1010.0443 [hep-th]].

[2] S. Sachdev, *Quantum Phase Transitions*, 2nd edition, Cambridge University Press (2011).

[3] D. Chowdhury, S. Raju, S. Sachdev, A. Singh and P. Strack, "Multipoint correlators of conformal field theories: implications for quantum critical transport," Phys. Rev. B **87**, 085138 (2013) [arXiv:1210.5247 [cond-mat.str-el]].

[4] J. Erdmenger and H. Osborn, "Conserved currents and the energy momentum tensor in conformally invariant theories for general dimensions," Nucl. Phys. B **483**, 431 (1997) [hep-th/9605009].